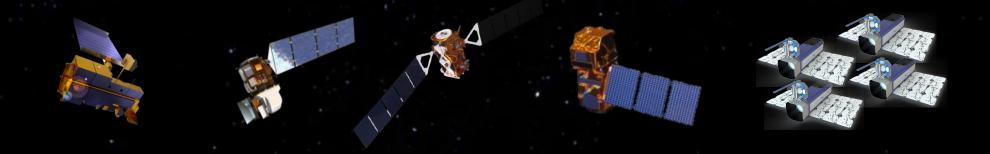
# Planet Fusion Monitoring:

Next generation ARD via a CubeSat enabled sensor fusion approach



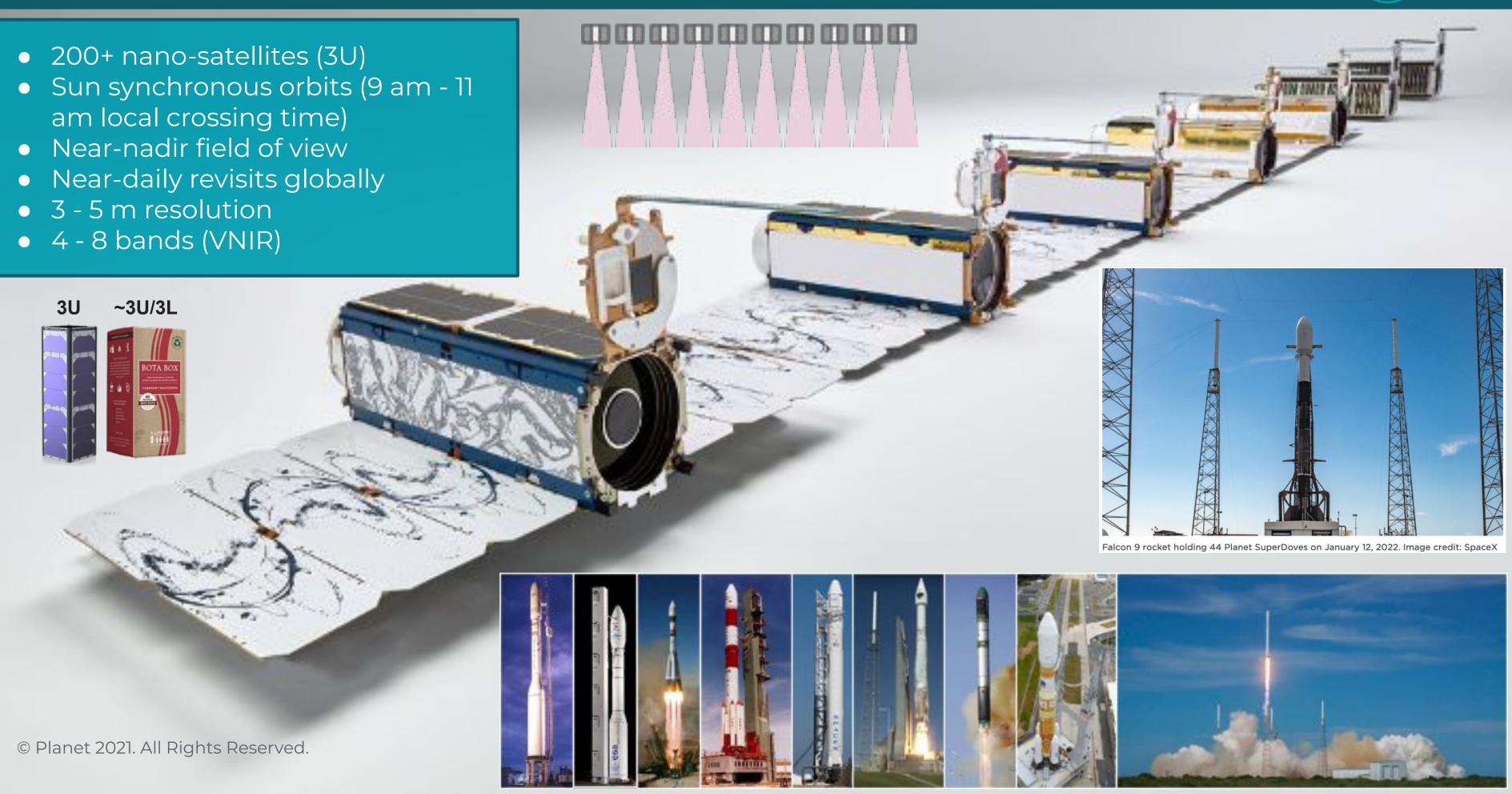
Rasmus Houborg (rasmus.houborg@planet.com)

**JACIE 2022** 



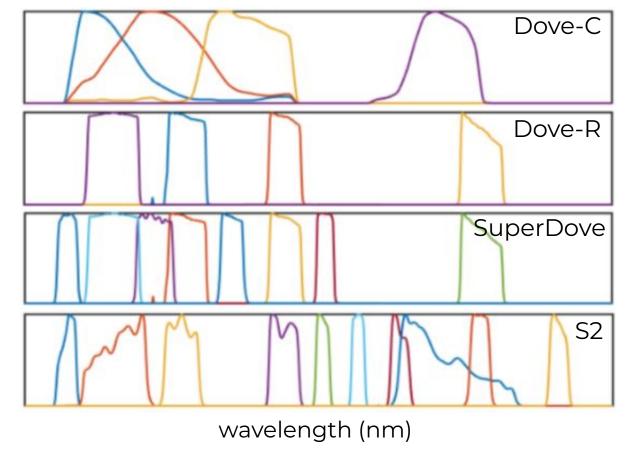
## Rise of the CubeSat and Distributed Constellations



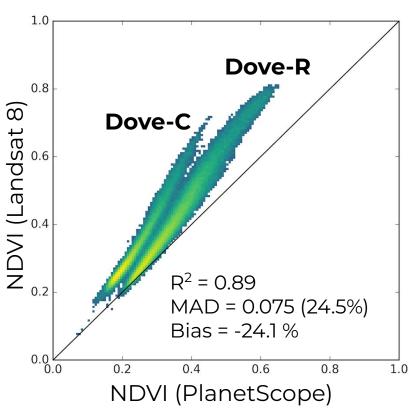


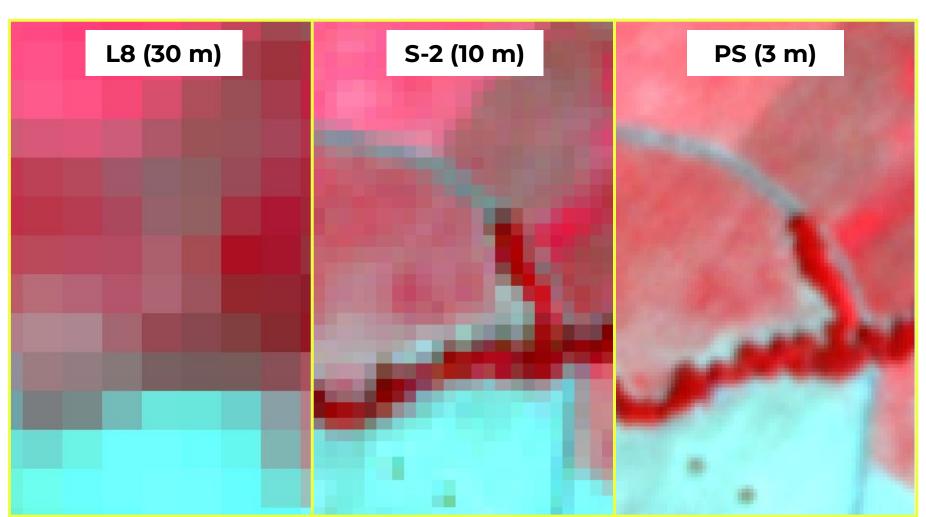
# Interoperability is usability

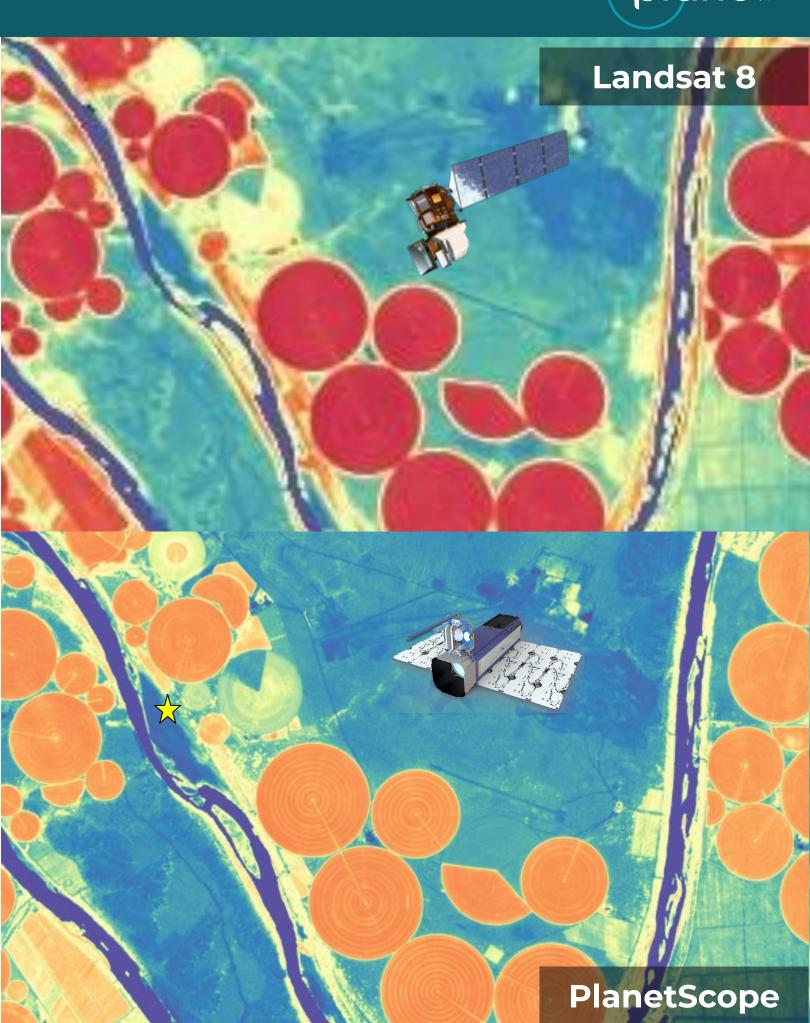




Relative Spectral Response







## What is Planet Fusion?

### Fusion attempts to take ARD to the next level

#### • Radiometric harmonization

- Fusion uses an implementation of CESTEM to align all sensor inputs to Sentinel 2 radiometry
- The Framework for Operational Radiometric Correction for Environmental Monitoring (FORCE) is used to generate a combined L8 and S2 Surface Reflectance product to use as the target "gold" reference
- The harmonization is spatially and temporally explicit and can account for significant spectral non-linearities between the input and target radiometry
- Fusion exploits a deep temporal stack of L8, S2, and MODIS/VIIRS SR data to detect outliers and perform a very robust and day-specific calibration

#### Geometric harmonization

 Rigorous co-registration and bundle adjustment routines are used to ensure pixel aligned imagery

### • Deep cleaning/cloud and shadow masking

- Rigorous, temporally driven, cloud and cloud shadow detection
- Rigorous data clean-up while preserving temporal information content

#### Remote Sensing of Environment 209 (2018) 211–226

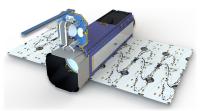


A Cubesat enabled Spatio-Temporal Enhancement Method (CESTEM) utilizing Planet, Landsat and MODIS data



Rasmus Houborg<sup>a,\*</sup>, Matthew F. McCabe<sup>b</sup>

#### **Enabled by CubeSats**



#### Powered by ML

### Sensor agnostic ARD



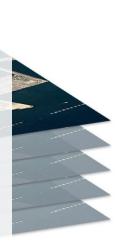
#### Sensor data fusion

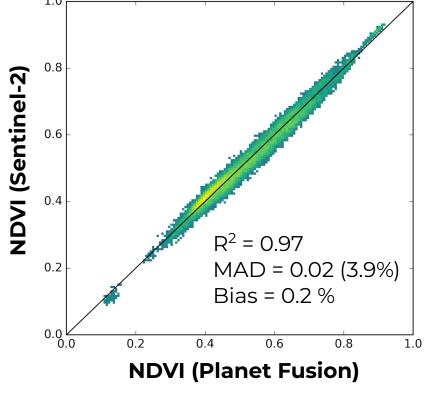


PlanetScope LANDSAT-8 Sentinel-2

Sentinel-1

MODIS VIIRS



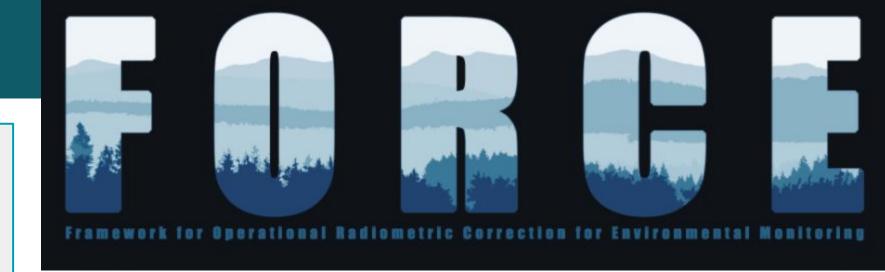


#### Gap-filling

- Daily (3 m) SR estimation using a rigorous spatio-temporal interpolation approach with a predictive component for near real-time production
- Integration of S-2 and L8 (and soon SAR) to help fill gaps in PlanetScope coverage

## FORCE in Planet Fusion

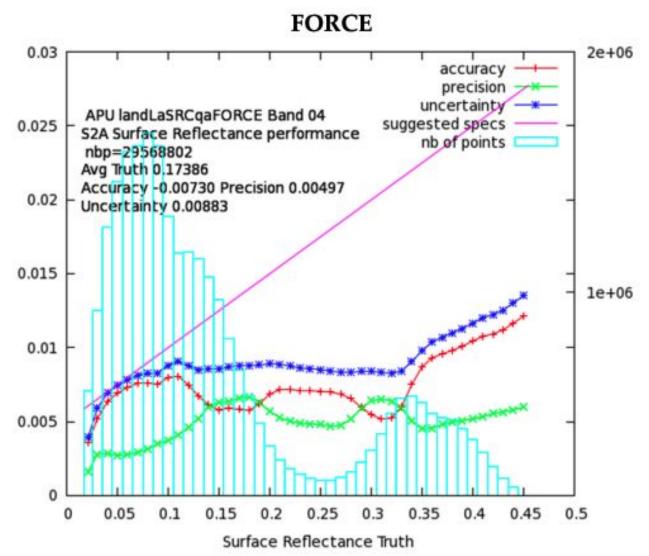
- Planet Fusion uses an in-house implementation of the Framework for Operational Radiometric Correction for Environmental Monitoring (FORCE) for producing Sentinel-2 (a/b) and Landsat 8 surface reflectance data:
  - Based on an implementation of **5S** (Simulation of the Satellite Signal in the Solar Spectrum) RTM code
  - Aerosol Optical Thickness (AOT) is estimated from the imagery using a dark object based approach
  - Water vapor content is either estimated on a pixel-specific basis (Sentinel-2) or derived from a global MODIS-based database (Landsat 8)
  - Clouds and shadows are detected using a modified version of Fmask that exploits parallax effects to improve detections for Sentinel-2 images
  - Includes topographic corrections and view angle normalization
- Sentinel-2 and Landsat 8 is mapped onto the UTM-based Military Grid Reference System with a 30 m spatial resolution
- A spectral **bandpass adjustment** (Claverie et al. 2018) is applied to Landsat 8 **to align with Sentinel-2 radiometry**
- Additional cloud and shadow detection/verification is done using the temporally-driven Planet Fusion detection approach



Article

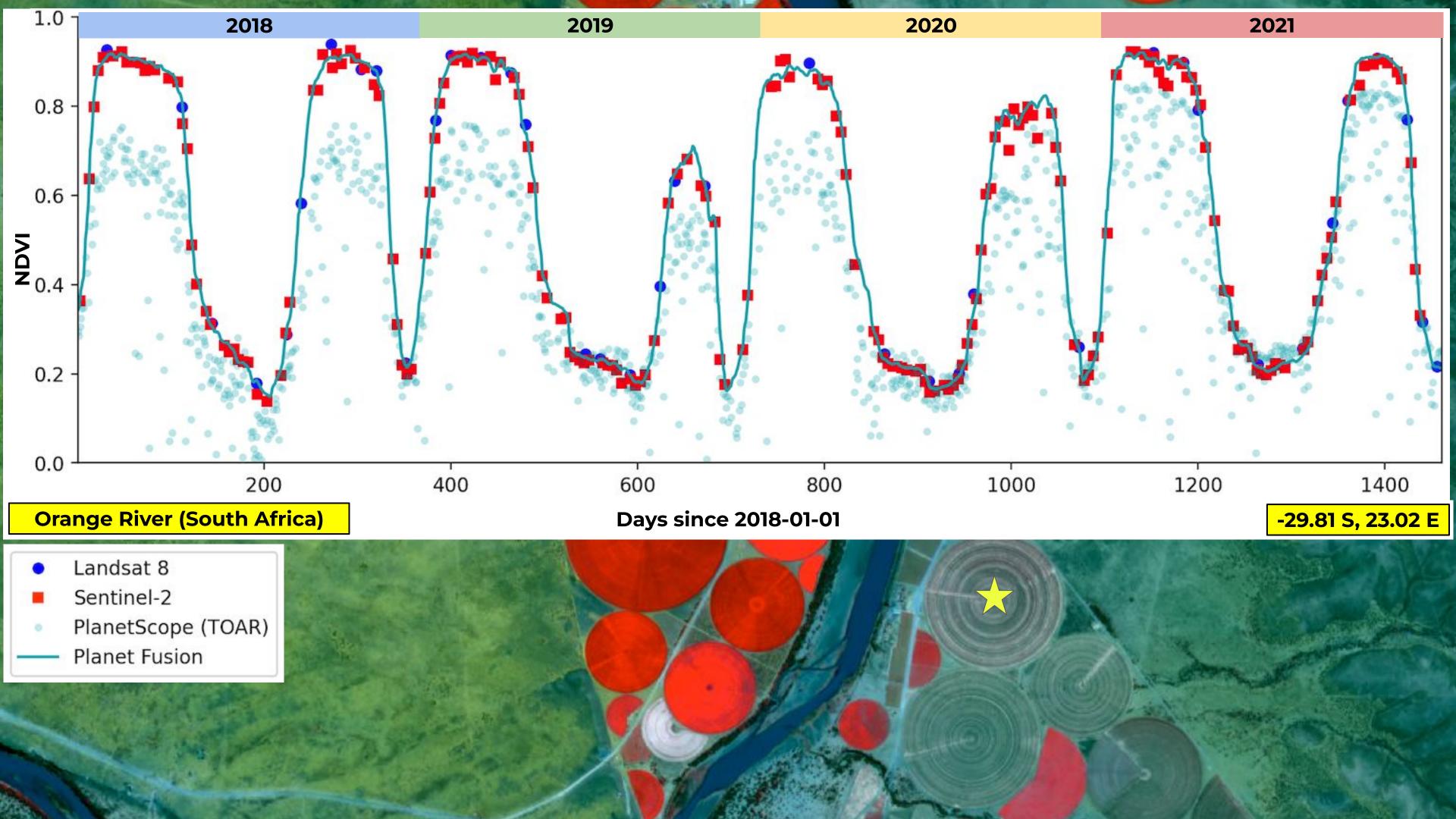
## **Atmospheric Correction Inter-Comparison Exercise**

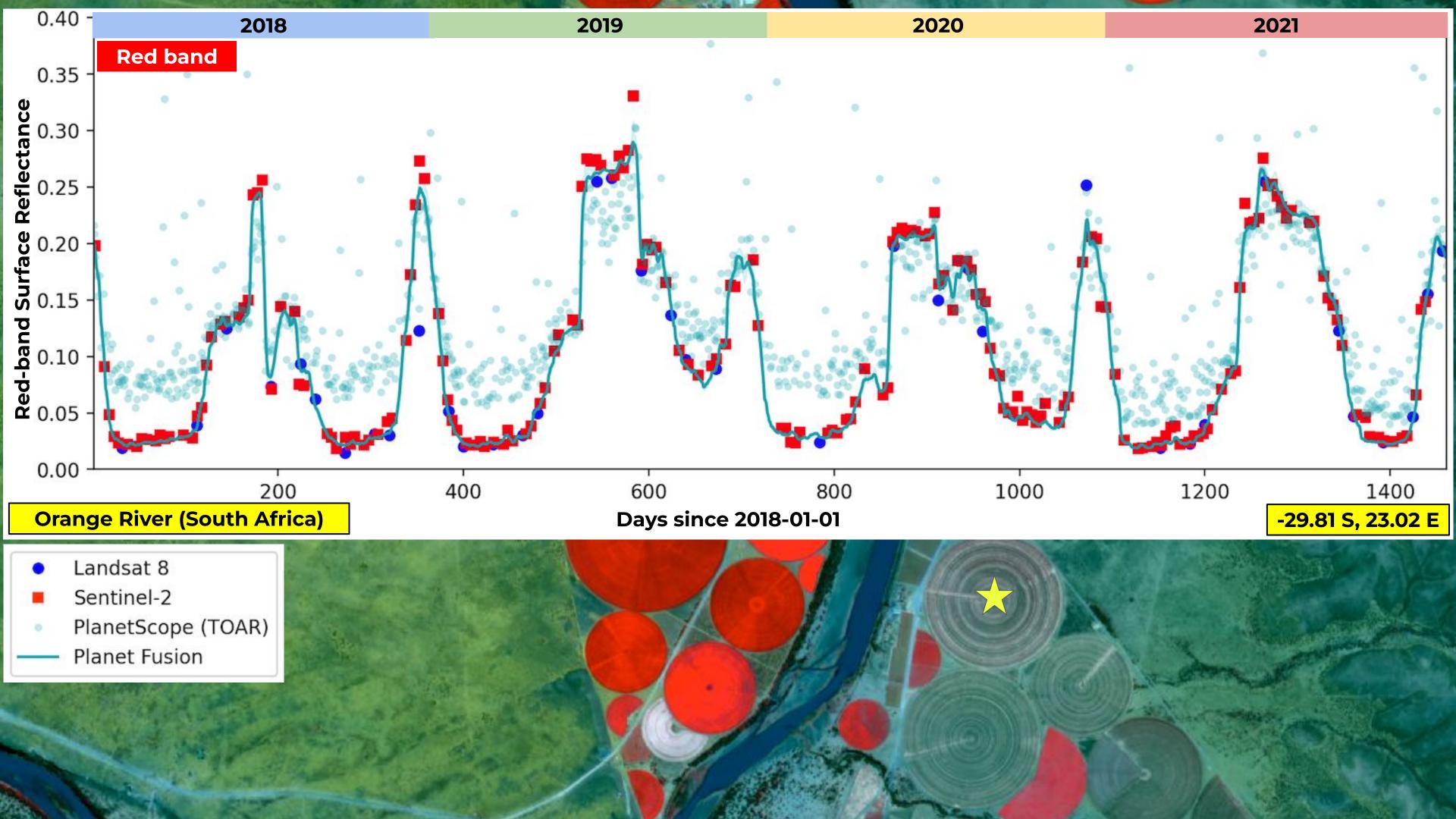
Georgia Doxani <sup>1,\*</sup>, Eric Vermote <sup>2,\*</sup>, Jean-Claude Roger <sup>2,3</sup>, Ferran Gascon <sup>4</sup>, Stefan Adriaensen <sup>5</sup>, David Frantz <sup>6,†</sup>, Olivier Hagolle <sup>7</sup>, André Hollstein <sup>8</sup>, Grit Kirches <sup>9</sup>, Fuqin Li <sup>10</sup>, Jérôme Louis <sup>11</sup>, Antoine Mangin <sup>12</sup>, Nima Pahlevan <sup>2,13</sup>, Bringfried Pflug <sup>14</sup> and Quinten Vanhellemont <sup>15</sup>

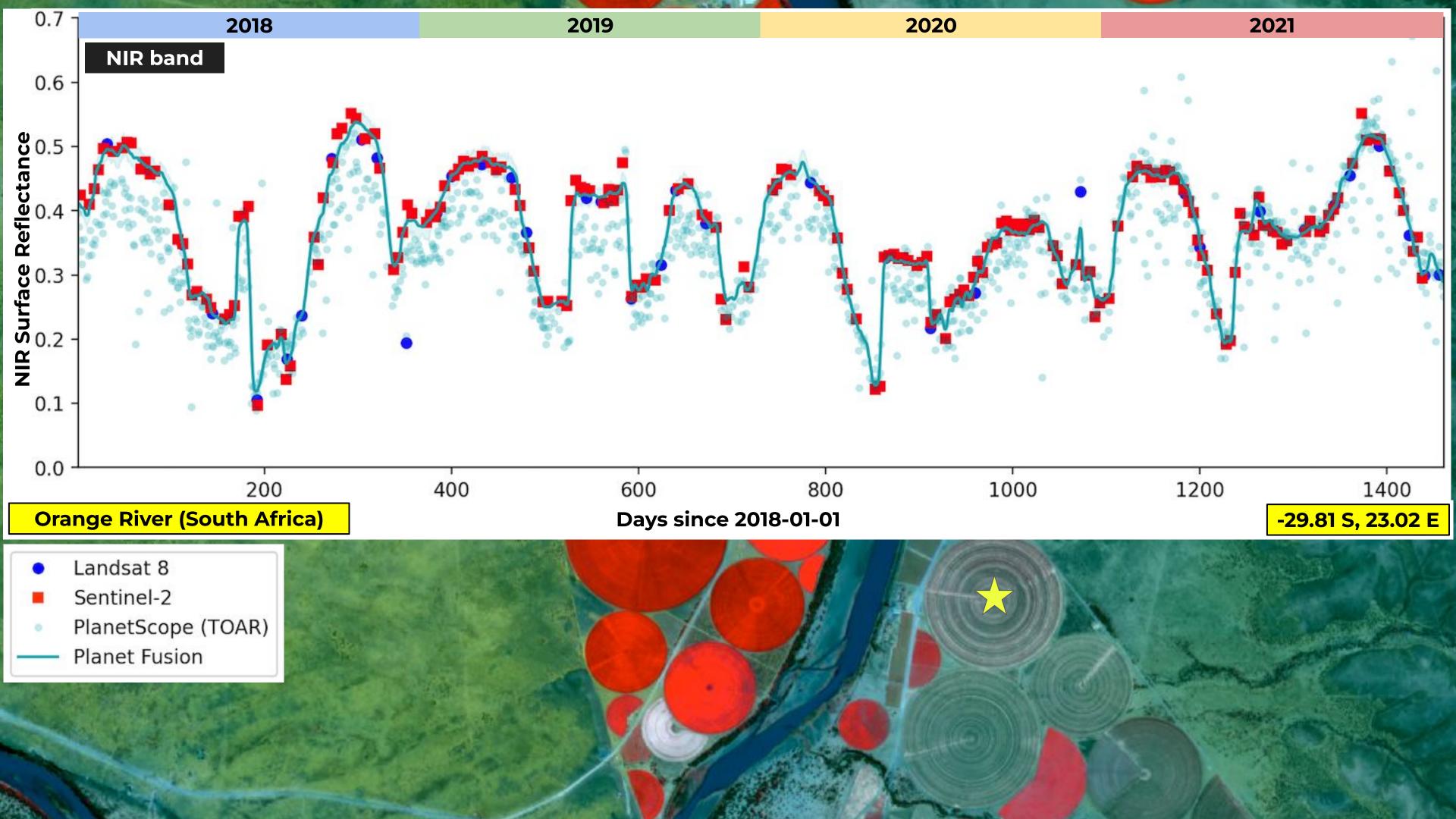


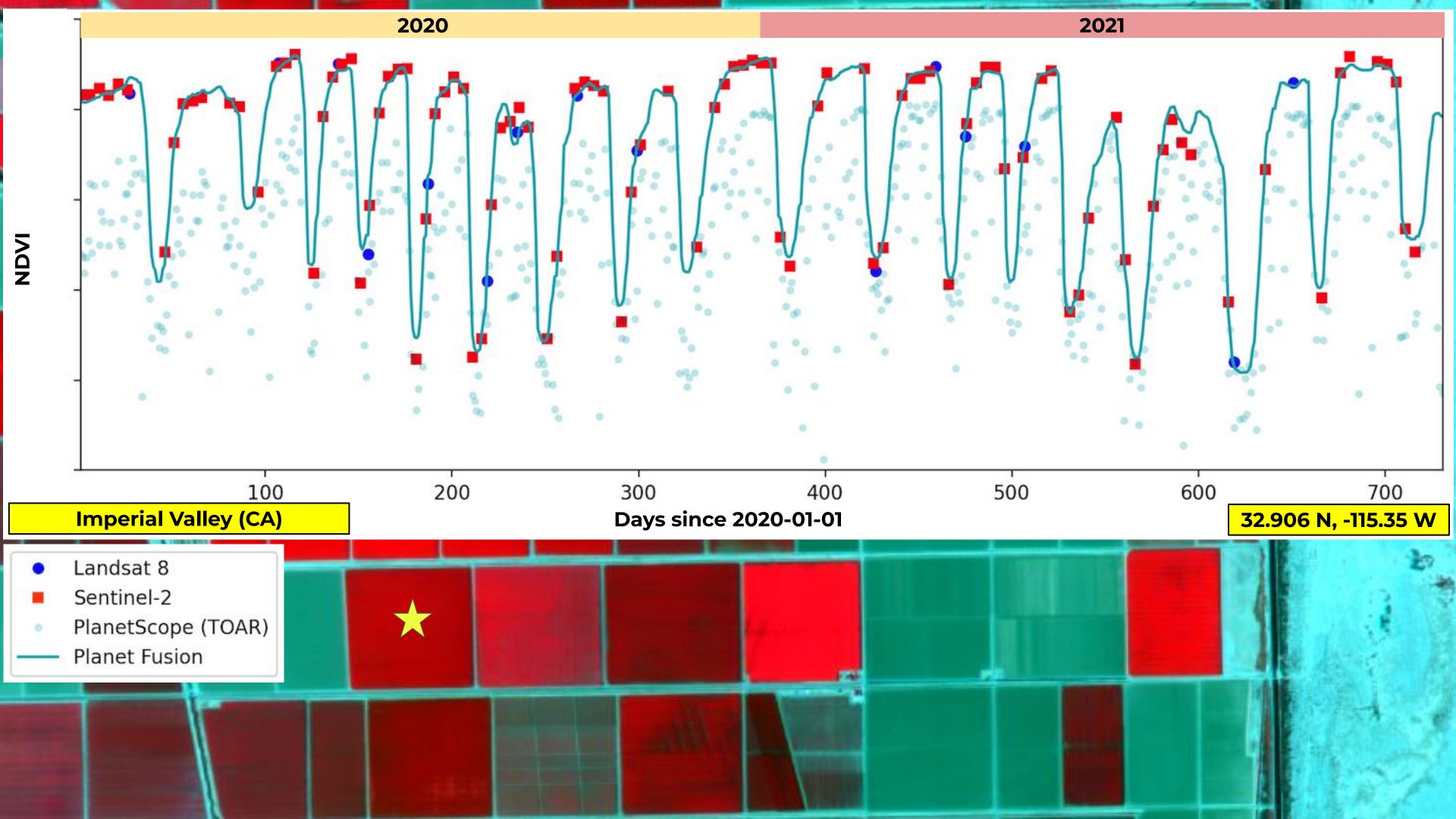






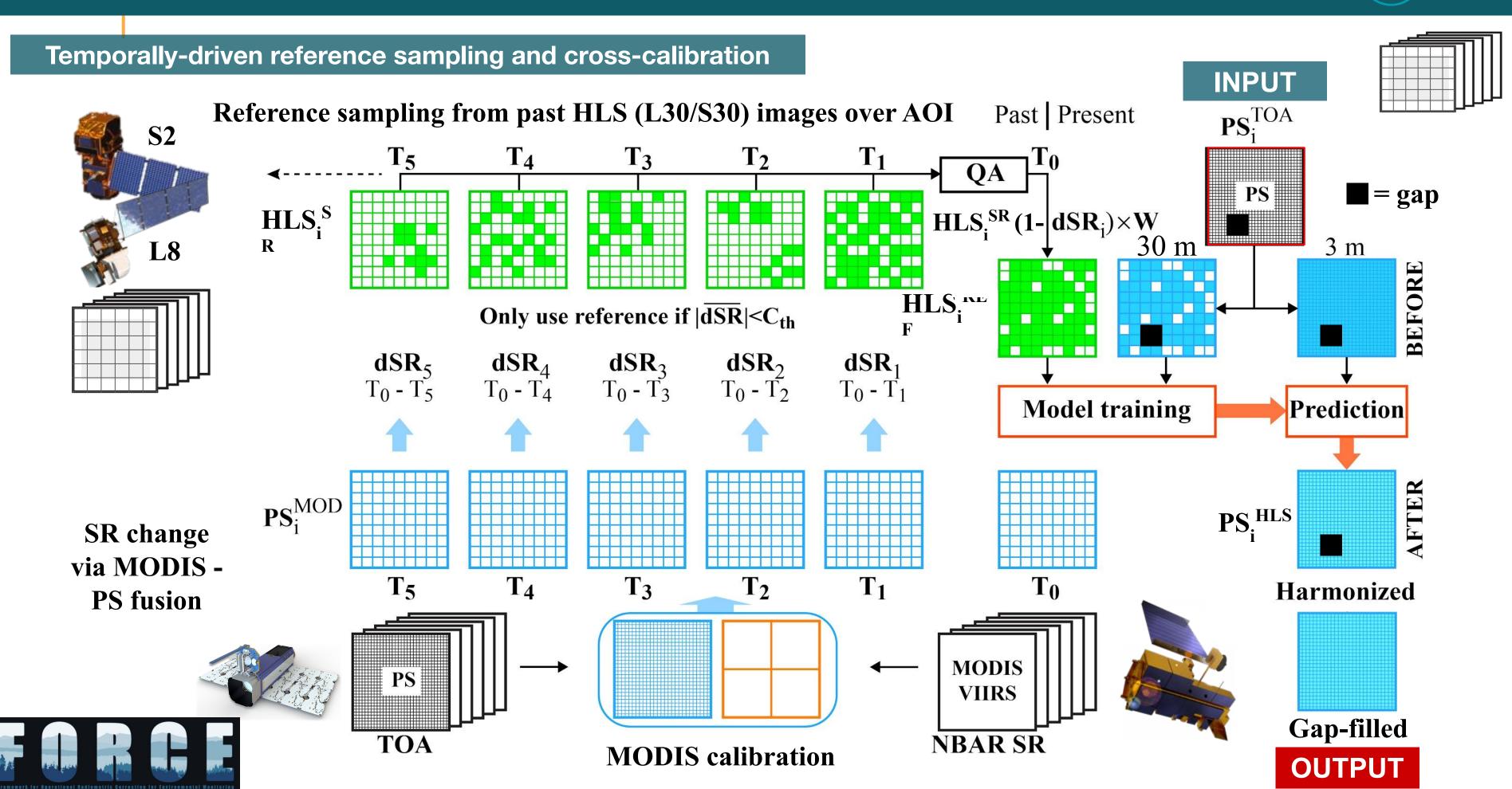






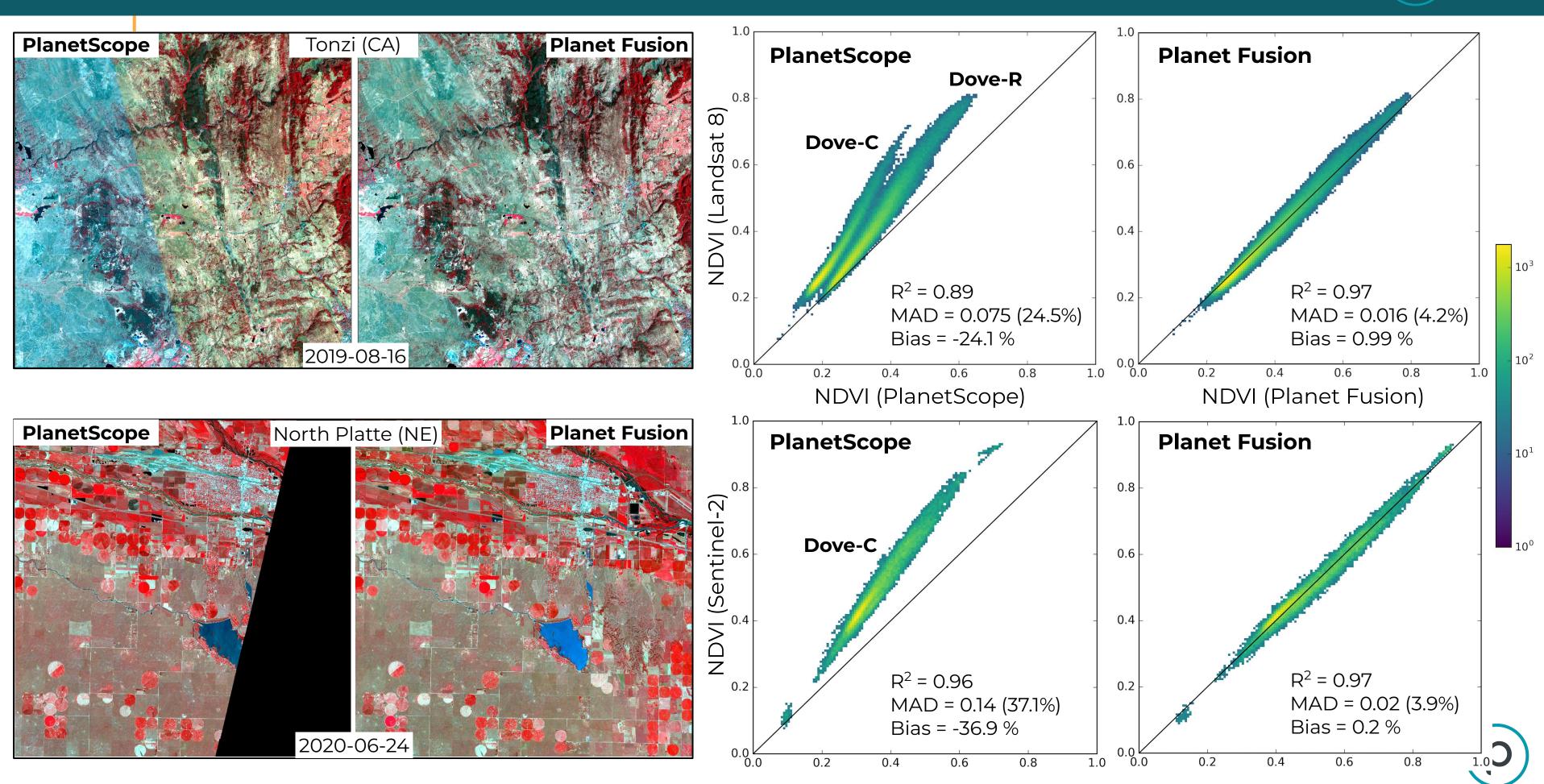
## Radiometric harmonization in Planet Fusion





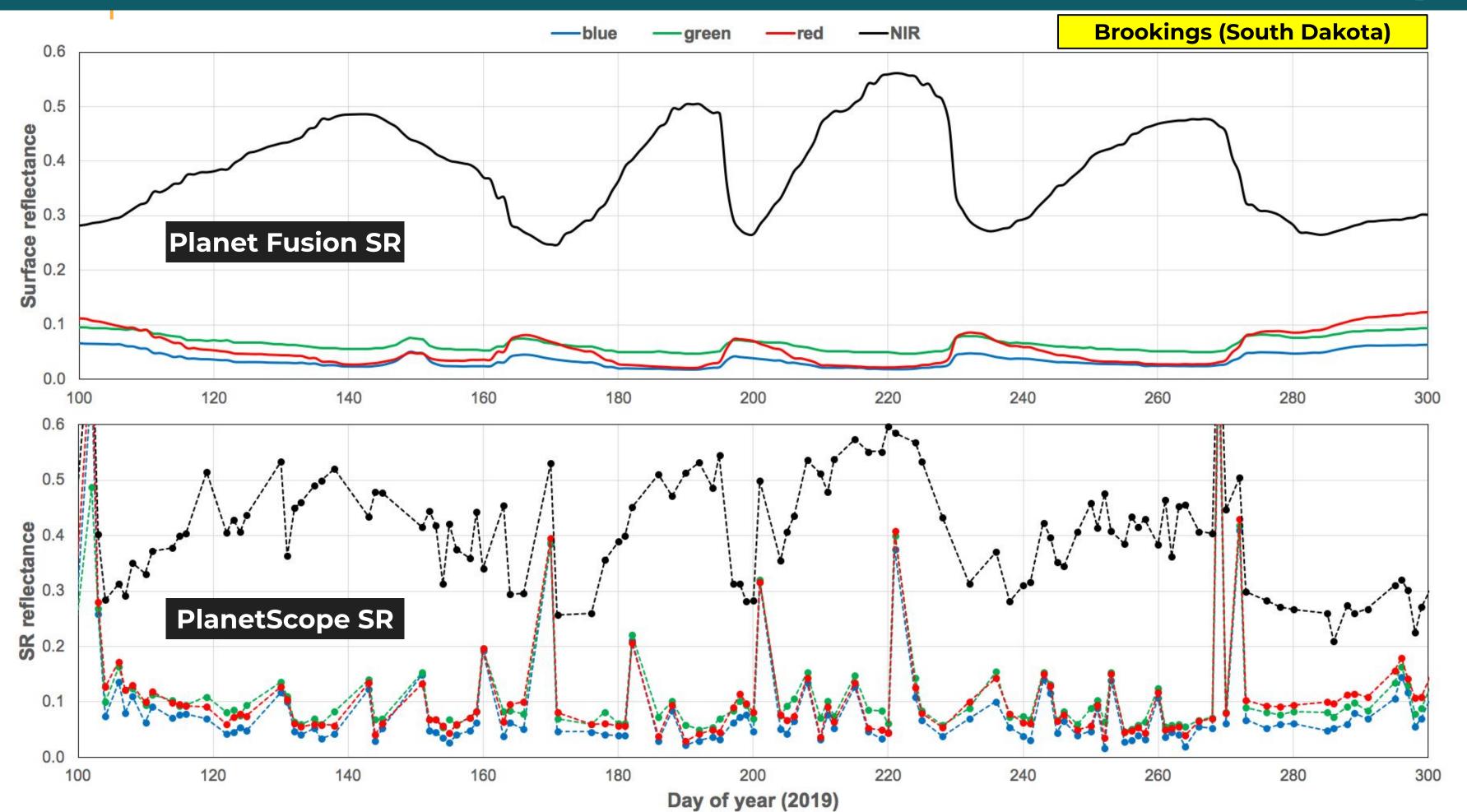
## Radiometric harmonization in Planet Fusion





## Radiometric harmonization in Planet Fusion



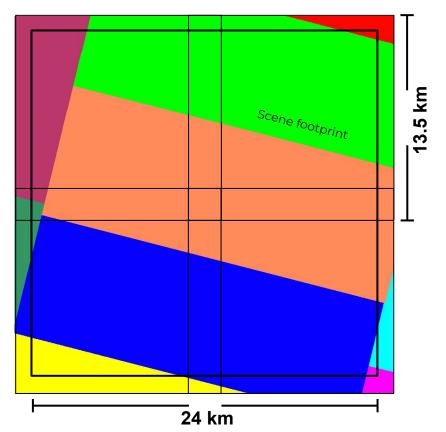




## Geometric harmonization in Planet Fusion



# Planet Fusion tile composition

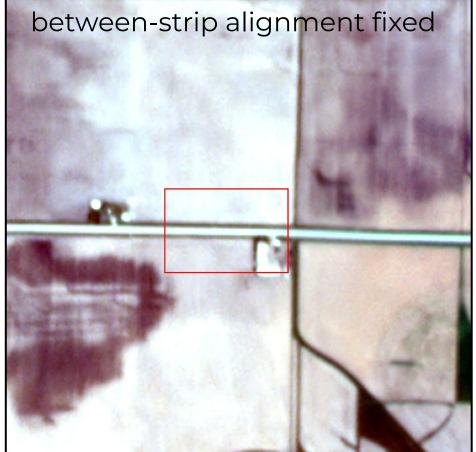


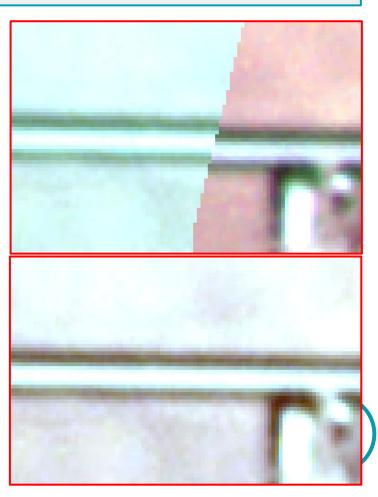
Within-strip alignment fixed



- A phase correlation technique (Guizar-Sicairos et al., 2008, scikit) is used to detect the global shift between two images with sub-pixel precision
- The clear-sky overlap between and within image strips is used to correct for band-specific sub-pixels shifts. This ensures that the PlanetScope scenes are properly aligned before compositing the tile
- L8/S2/MODIS/VIIRS data are sub-pixel aligned to a day coincident Planet Fusion chunk
- Pixel alignment in temporal space is performed using a rigorous bundle adjustment based approach
- In addition, a chunk-level co-registration against clear-sky S2 imagery is performed. This will reduce any offset that may exist between PS/PF and S2 imagery and between adjacent Fusion tiles
- Chunks are sub-pixel aligned before being merged to produce the tile







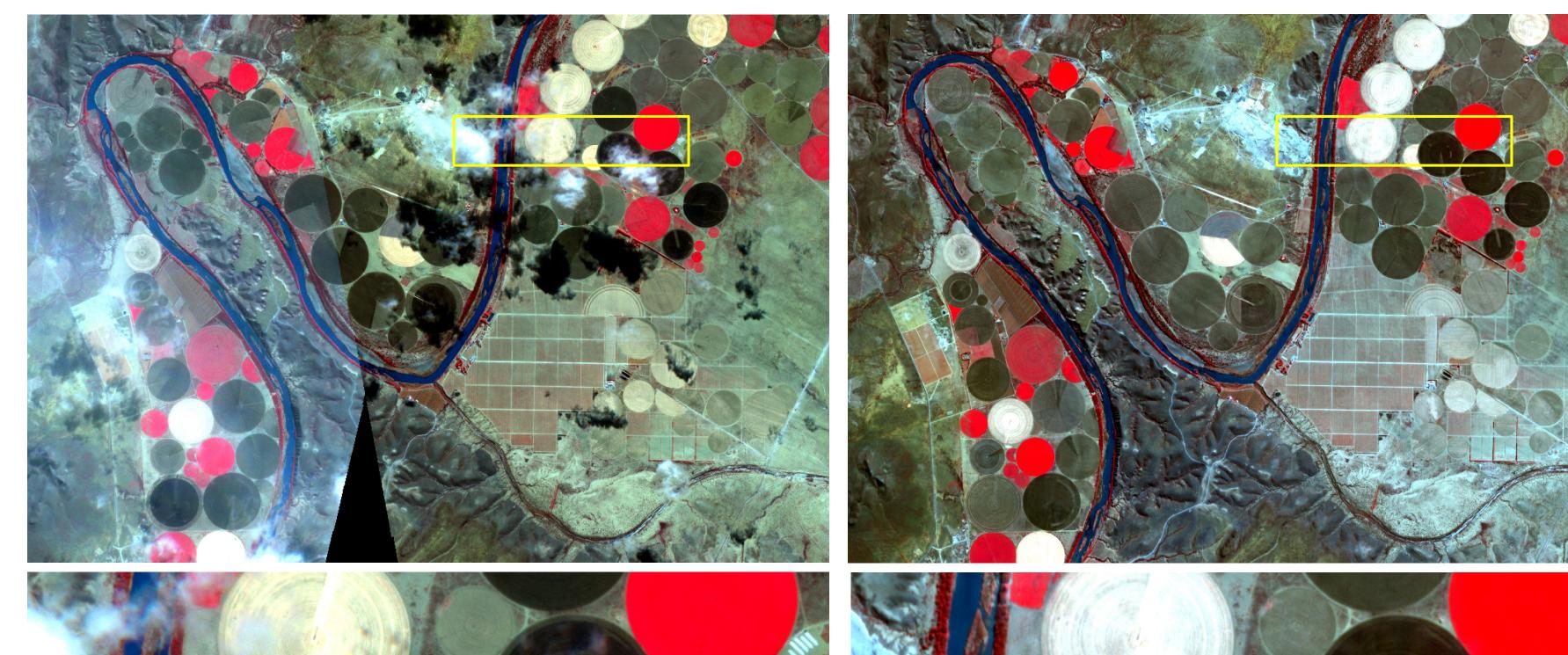


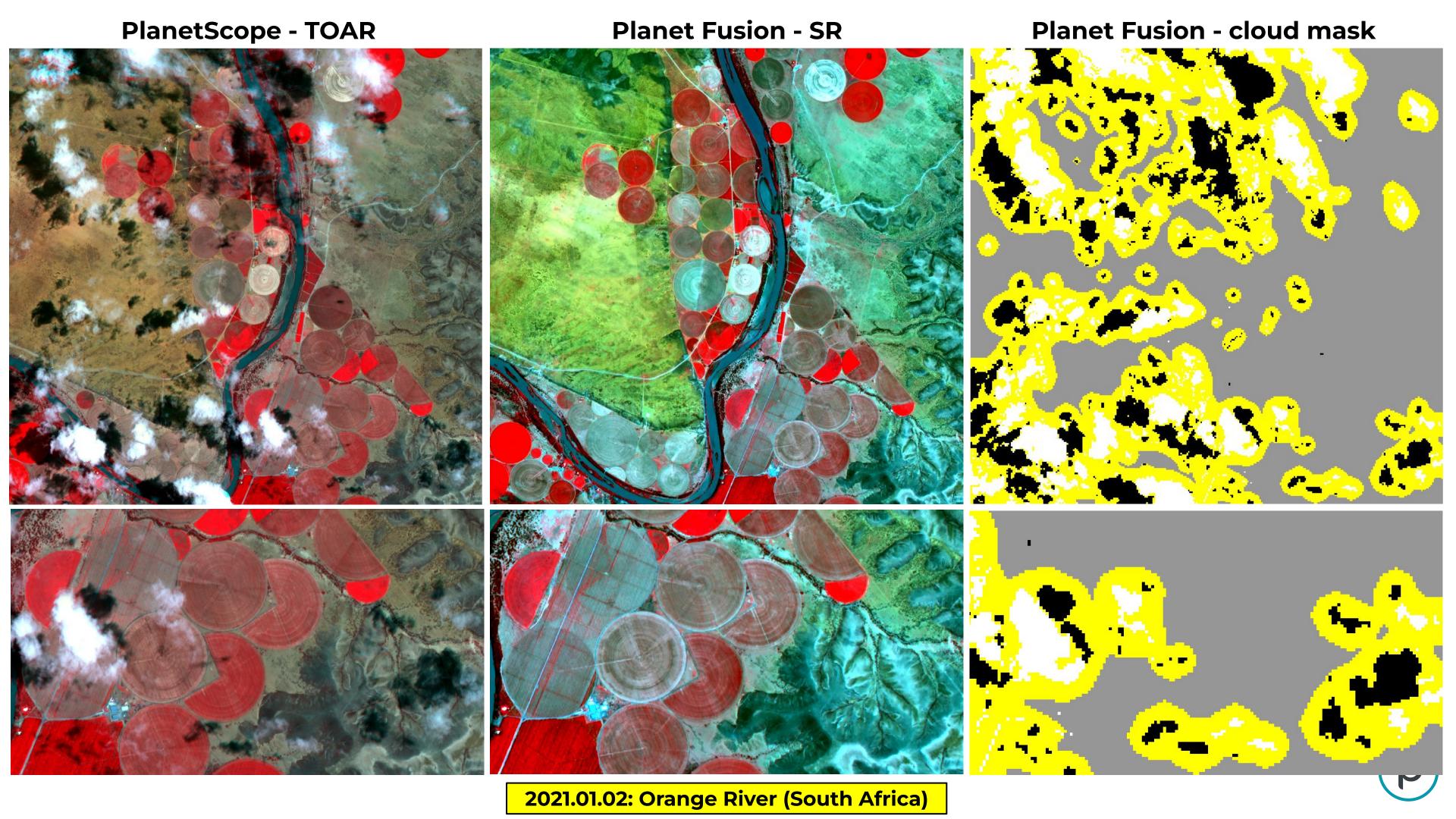
# Cloud masking and gap-filling in Planet Fusion

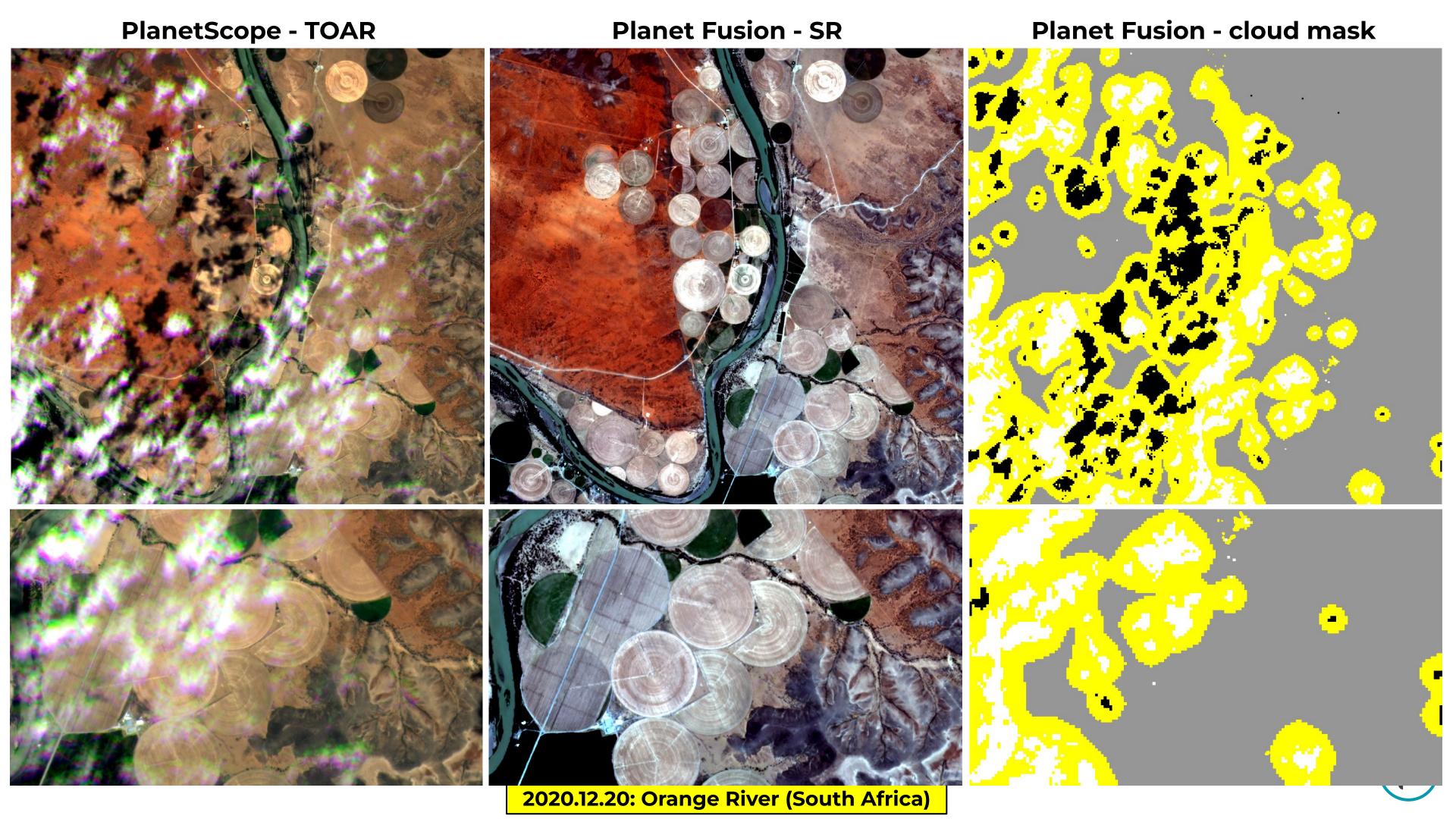


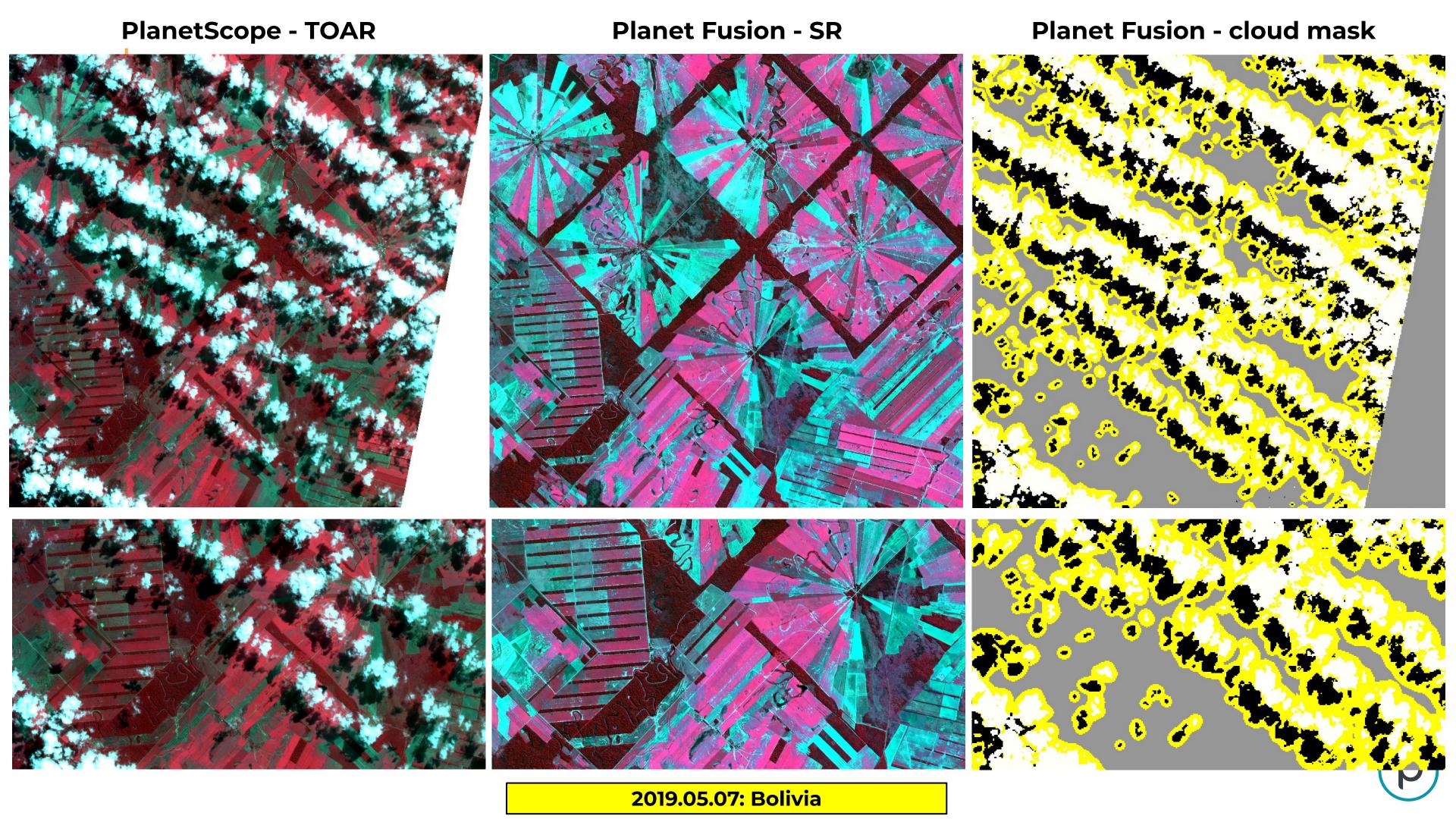
PlanetScope - TOAR

**Planet Fusion - SR** 

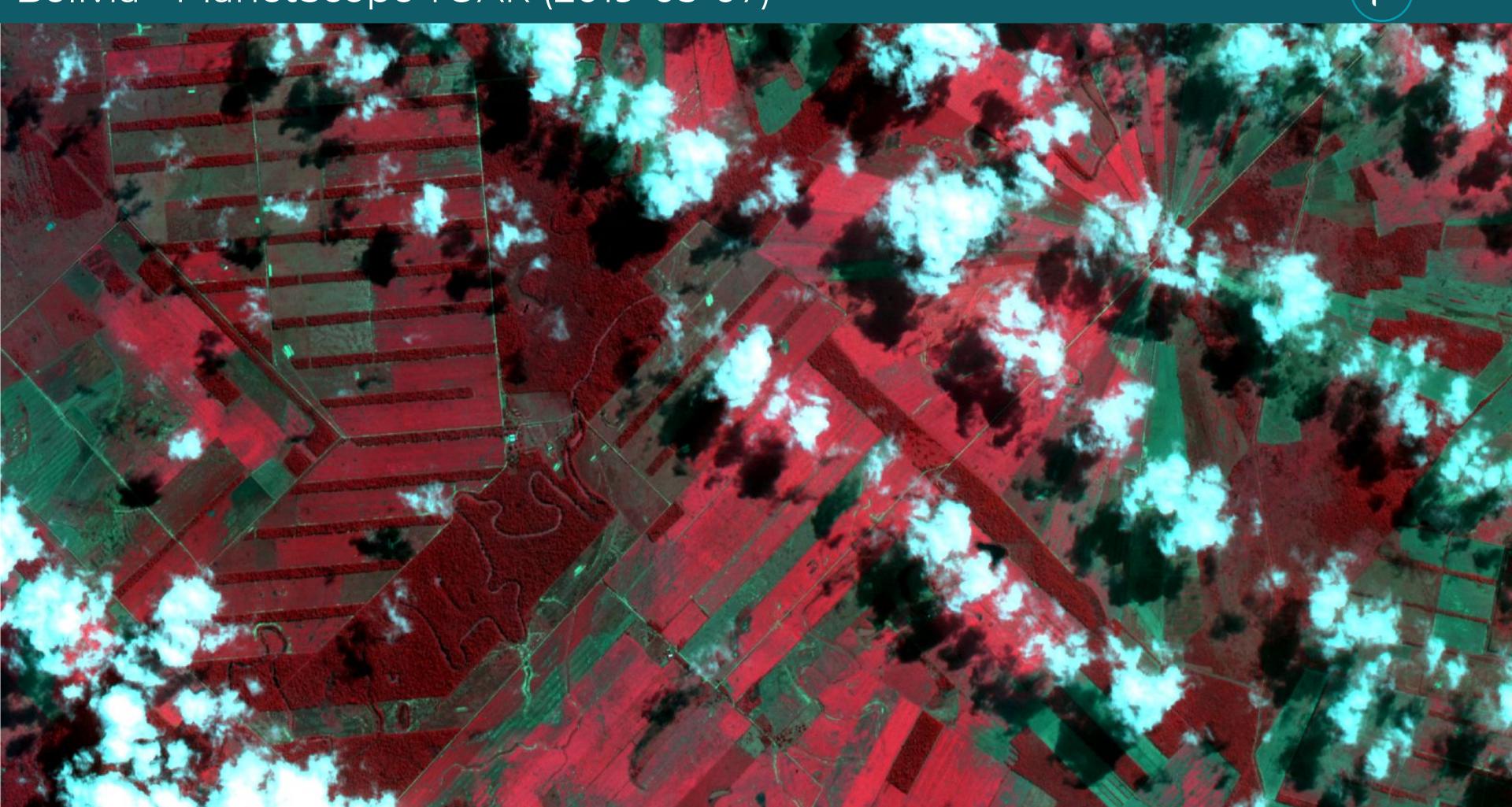








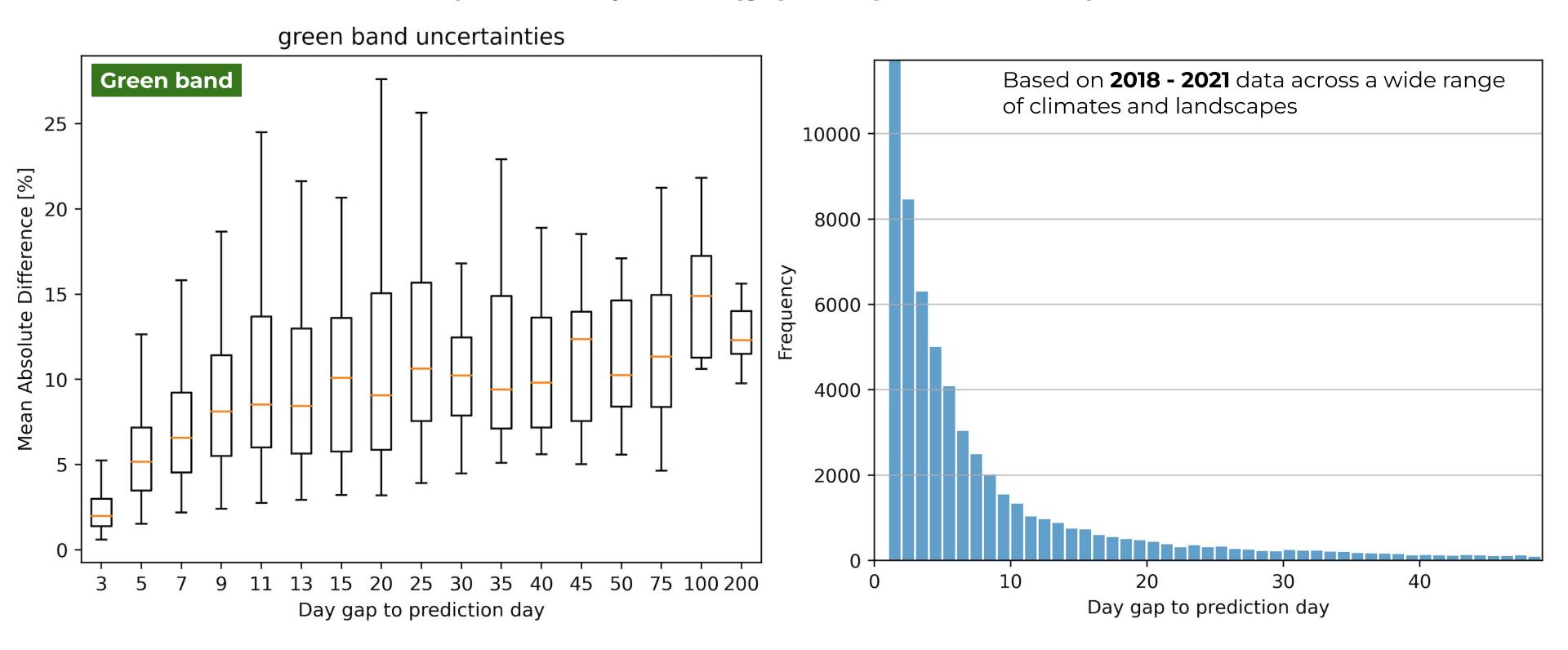
planet



## Gap-filled pixel uncertainties



## Intercomparison of synthetic (gap-filled) and observed pixel values

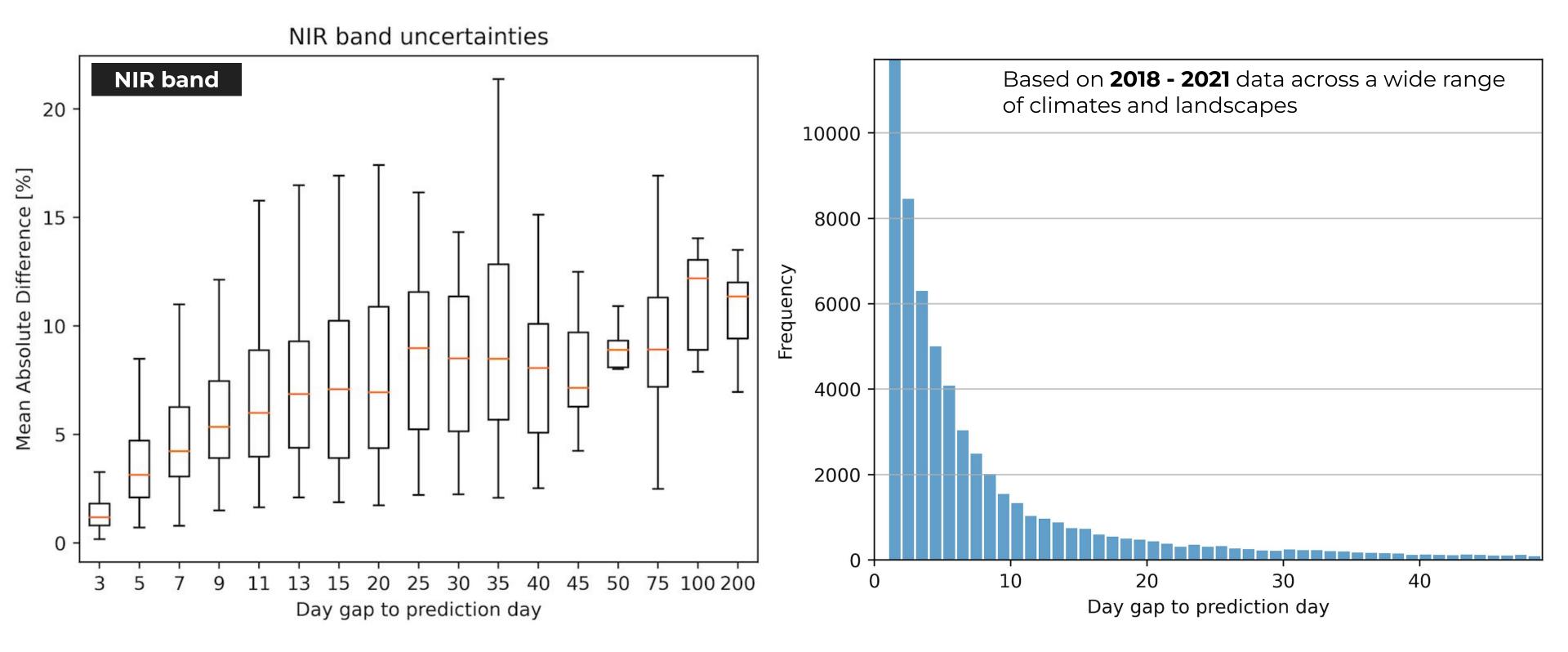




## Gap-filled pixel uncertainties

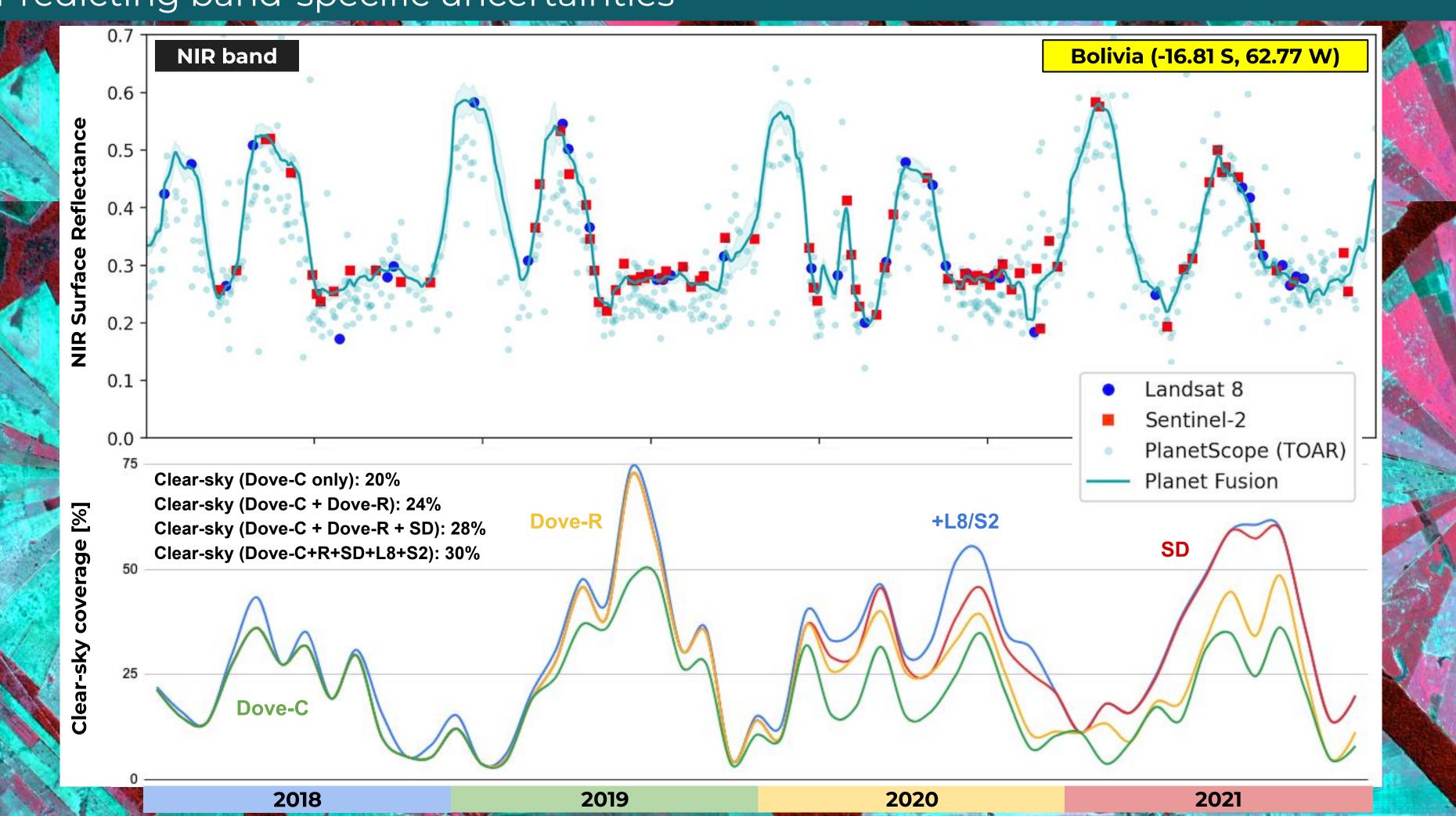


## Intercomparison of synthetic (gap-filled) and observed pixel values



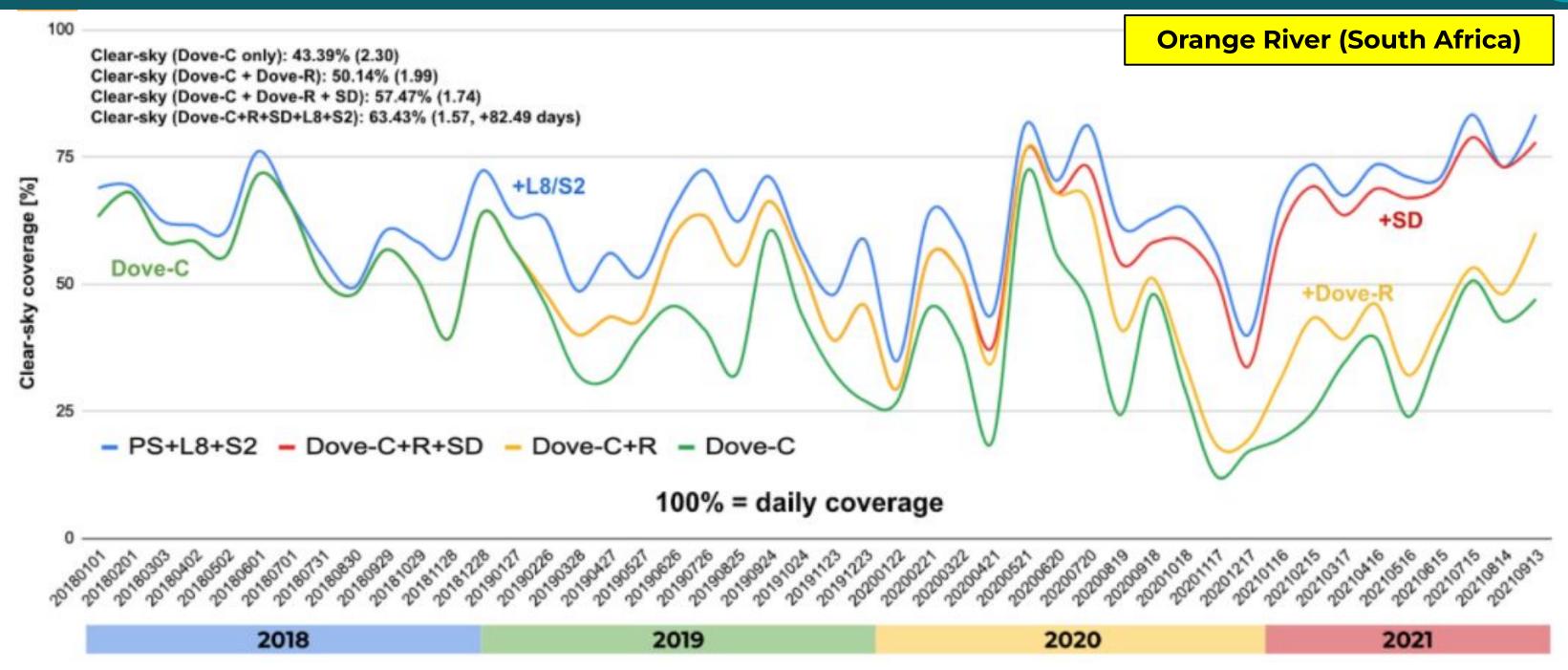


# Predicting band-specific uncertainties



# Clear-sky coverage scenarios

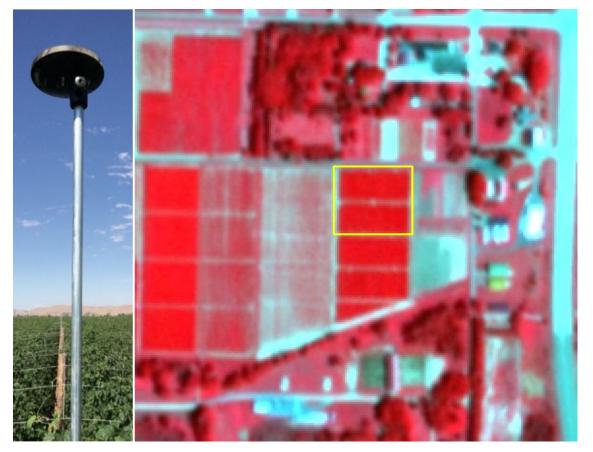


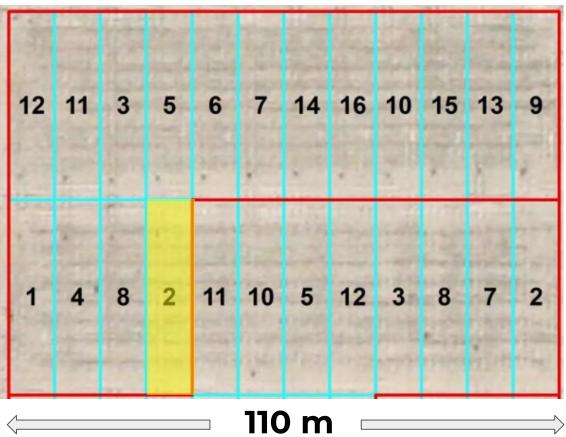


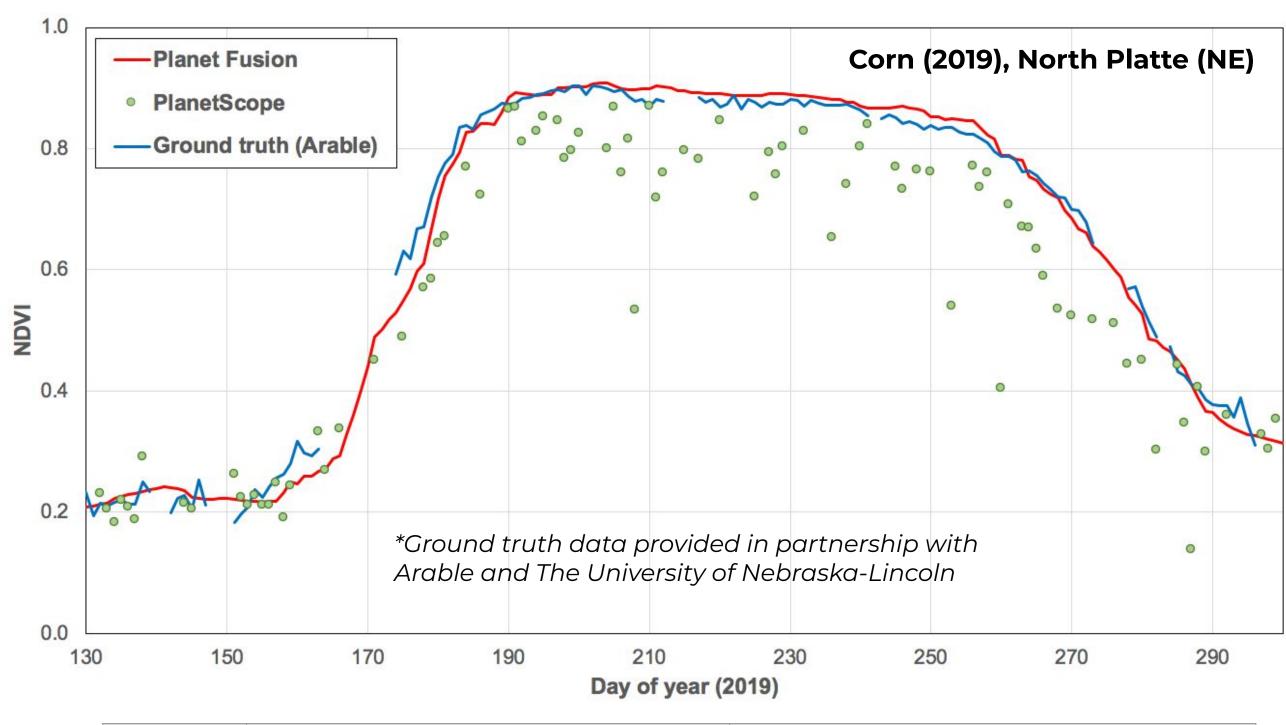
Source Imagery	Clear-Sky Coverage	Revisit time
Dove-C, Dove-R, SuperDove, Sentinel-2, Landsat 8	64%	1.57
Dove-C, Dove-R, SuperDove	58%	1.74
Dove-C, Dove-R	50%	1.99
Dove-C	43%	2.30

## Ground-based validation



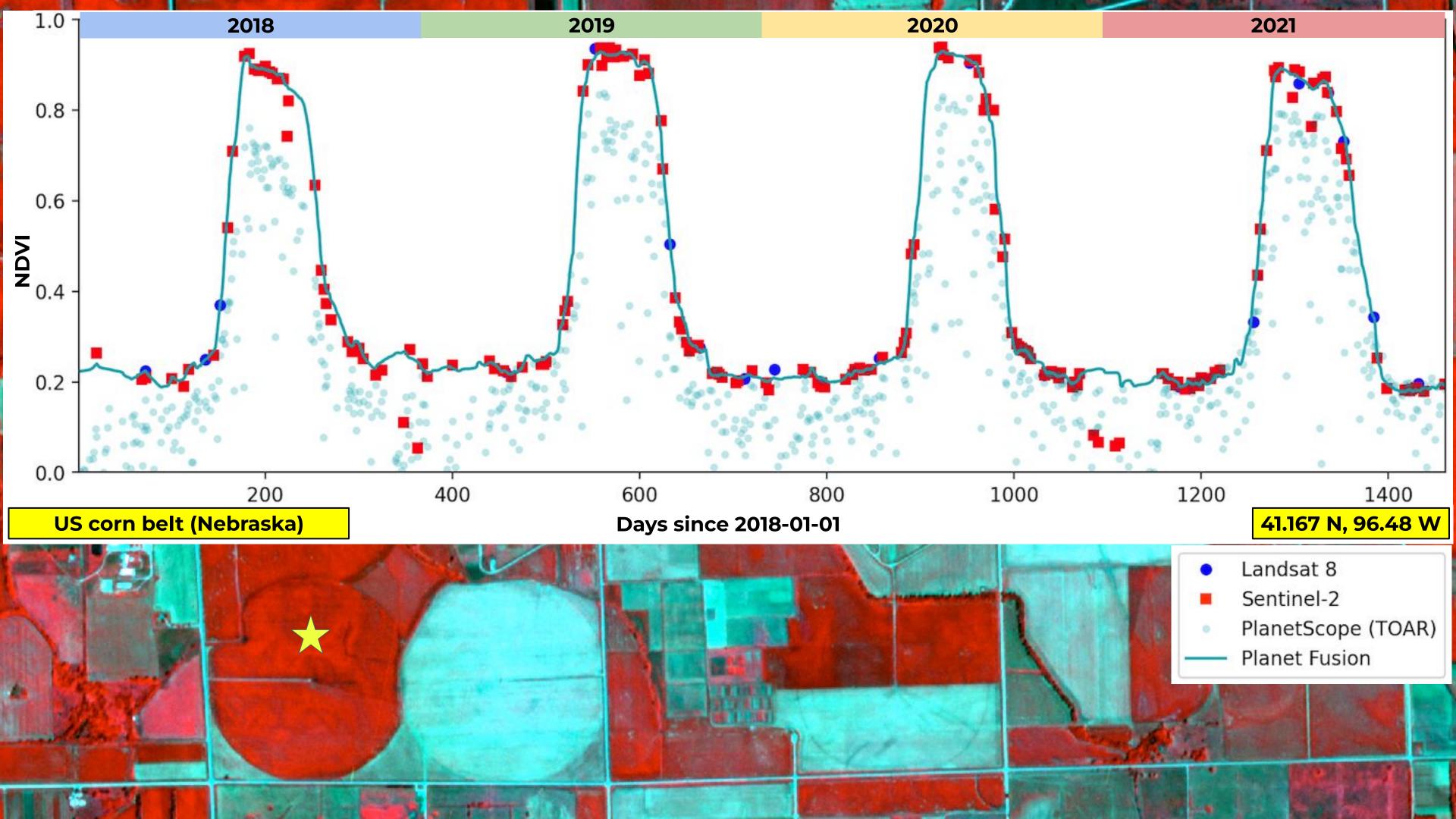


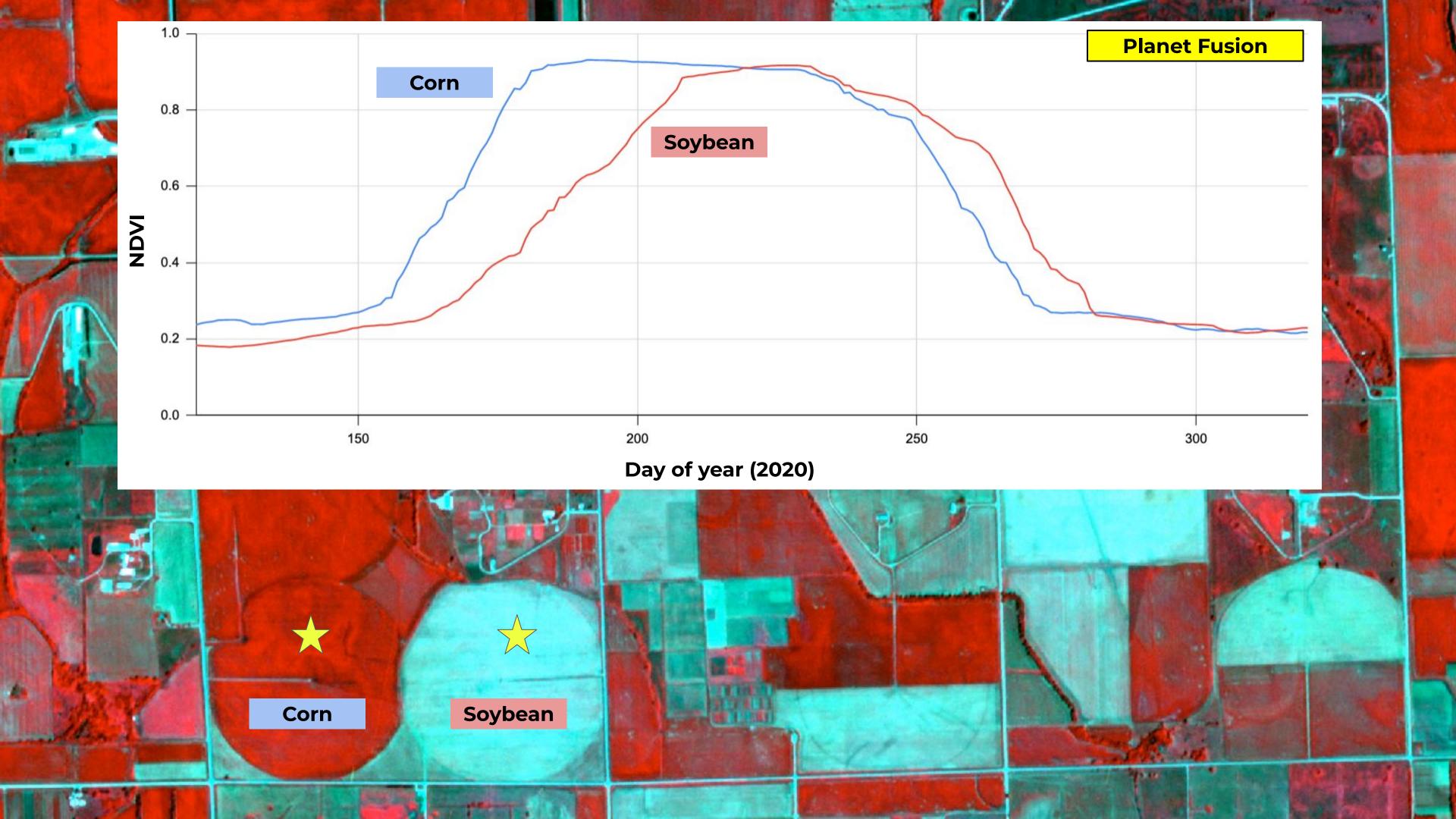


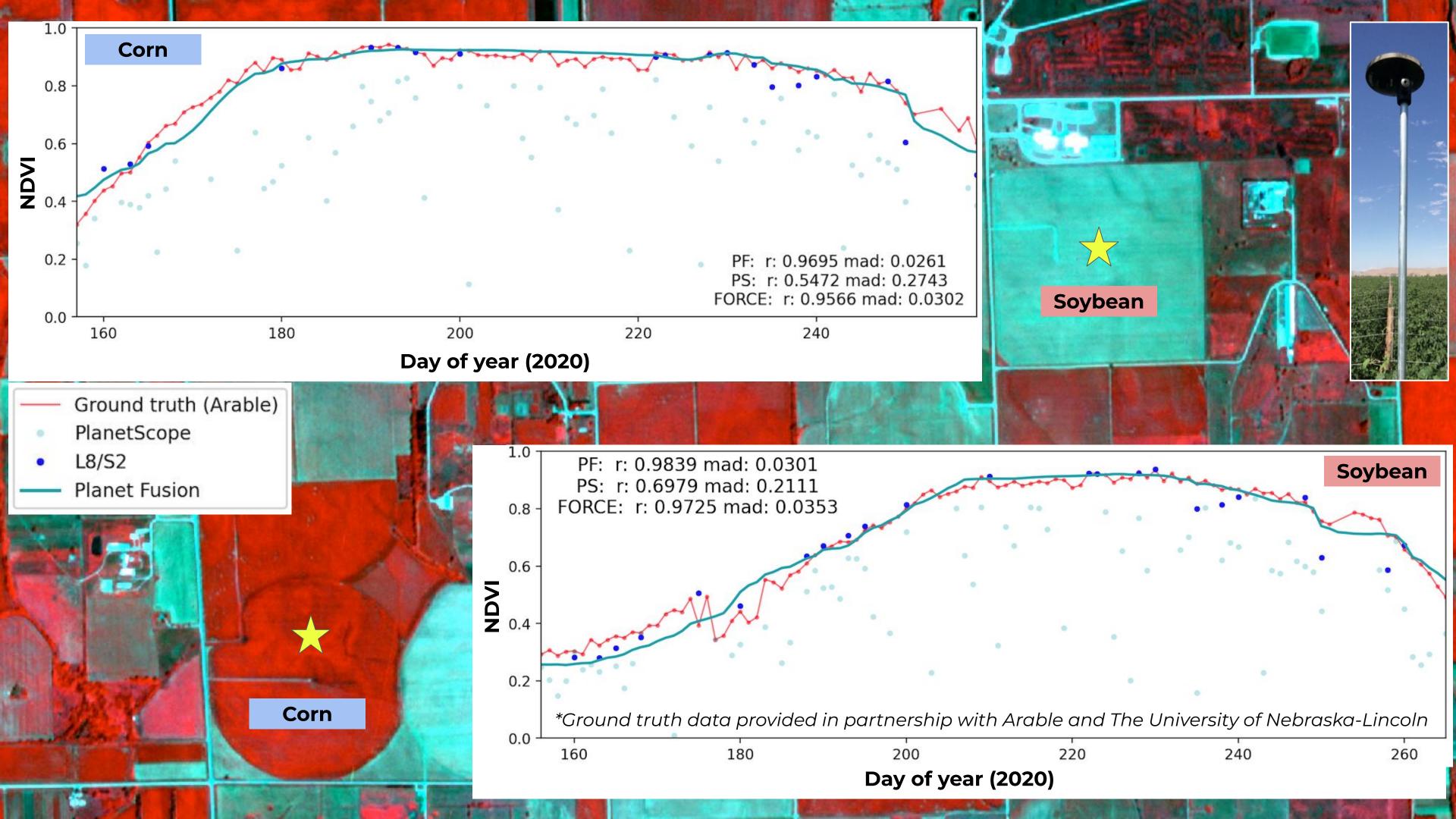


Metric	Arable vs PlanetScope	Arable vs Planet Fusion
r <sup>2</sup>	0.910	0.993
rMAD	0.086 (13.0%)	0.018 (2.7%)

Each blok ~ 9 m wide

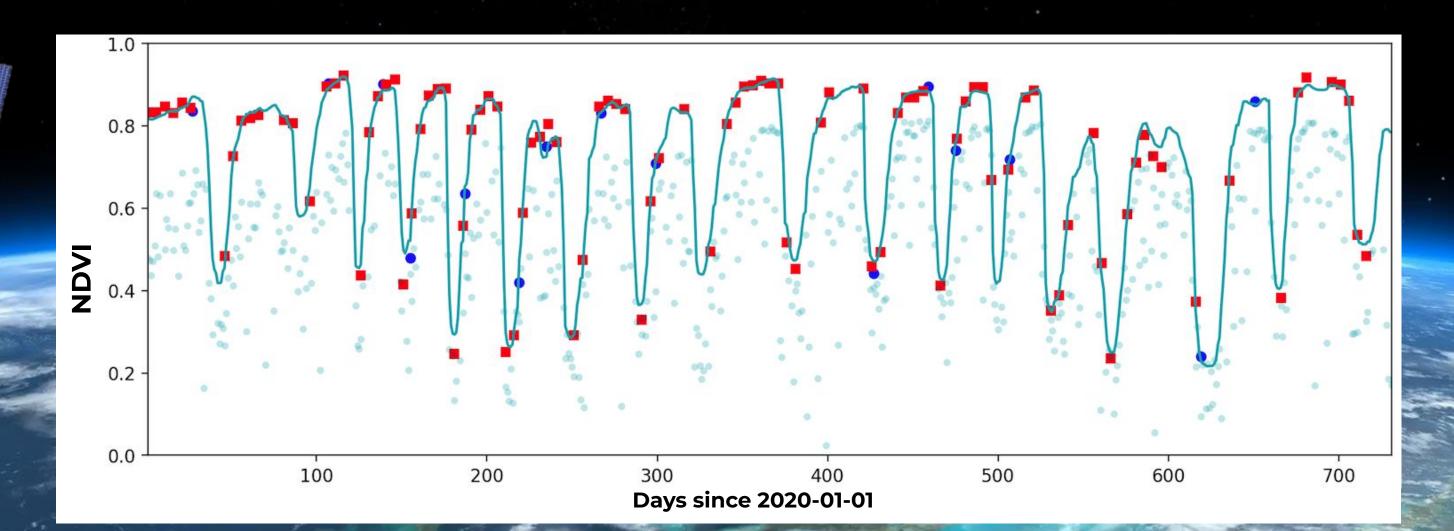




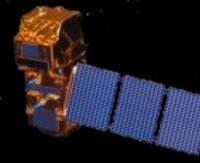




- Daily (gap-free) 4-band Surface Reflectance values delivered as gridded UTM tiles (24 km)
   x 24 km) with a 2-day latency
- Advanced radiometric harmonization which leverages rigorously calibrated third party sensors (MODIS/VIIRS, Landsat 8, and Sentinel-2) for full fleet interoperability
- Geometric harmonization to ensure pixel-aligned imagery
- Rigorous, temporally driven, cloud and cloud shadow detection
- Fusion of Sentinel-2 and Landsat 8 data to help fill gaps in PlanetScope coverage













- Optical SAR Fusion to improve performance and confidence estimates over cloud prone regions
- Adding additional spectral bands (e.g., red-edge)
- Evaluate consistency against other Surface Reflectance products (e.g., NASA HLS, ESA sen2cor, sen2like, USGS LaSrc)
- Expand validation framework against ground-based sensor networks
- Use Planet Fusion SR data as the foundation for deriving higher level products (e.g. LAI, ET)
- Collaborate with academic and industry partners to identify valuable and interesting use

cases of Planet Fusion



Agricultural and Forest Meteorology
Volume 313, 15 February 2022, 108736



Article | Open Access | Published: 09 June 2021

# CubeSats deliver new insights into agricultural water use at daily and 3 m resolutions

Bruno Aragon ☑, Matteo G. Ziliani, Rasmus Houborg, Trenton E. Franz & Matthew F. McCabe

Cubesat Constellations Provide Enhanced Crop Phenology And Digital Agricultural Insights Using Daily Leaf Area Index Retrievals.

Johansen K, Ziliani MG, Houborg R, Franz TE, McCabe MF

Preprint from **Research Square**, 13 Dec 2021

DOI: 10.21203/rs.3.rs-1134595/v1 PPR: PPR431416



Agricultural and Fore crop model

Volume 297, 15 Februar Matteo G. Ziliani <sup>a</sup>  $\stackrel{\boxtimes}{\sim}$  Muhammad U. Altaf <sup>a</sup>, Bruno Aragon <sup>b</sup>, Rasmus Houborg <sup>c</sup>, Trenton E. Franz <sup>d</sup>, Yang Lu <sup>e</sup>, Justin Sheffield <sup>e</sup>, Ibrahim Hoteit <sup>f</sup>, Matthew F. McCabe <sup>a</sup>

Early season prediction of within-field crop yield

variability by assimilating CubeSat data into a

Evaluation of four image fusion NDVI products against in-situ spectral-measurements over a heterogeneous rice paddy landscape

Juwon Kong <sup>a, h</sup>, Youngryel Ryu <sup>a, b, c, h</sup> ♀ , Yan Huang <sup>b</sup>, Benjamin Dechant <sup>c</sup>, Rasmus Houborg <sup>d</sup>, Kaiyu Guan <sup>e, f</sup>, Xiaolin Zhu <sup>g</sup>

